LETTERS TO THE EDITORS

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World-wide Frequency and Time Comparisons by Means of Radio Transmissions

For many years standards of frequency have been made available to users over a wide area by means of radio transmissions, the carrier waves of which are controlled by the standard; and the frequencies of 2·5, 5, 10, 15, 20 and 25 Mc./s. have been allocated to this purpose by international agreement. Frequency standards can now be maintained in operation with a stability of a few parts in 10^9 per month, and they can be intercompared in the laboratory with a precision of $\pm$ 1 part in 10^{10}. There is, however, a loss of accuracy due to transmission, and although it has been found that $\pm$ 1 part in 10^8 can be achieved under suitable conditions, the accuracy in general is limited to about $\pm$ 2 parts in 10^7 because progressive movements of the ionospheric layers at which the waves are reflected cause a steadily increasing or decreasing path-length and a consequent Doppler-effect frequency change. In view of this limitation, an experimental transmission on 60 kc./s. was included in the United Kingdom service when this was resumed in 1950, with the call sign *MSF*. The ionospheric layer at which such low-frequency waves are reflected is known to be comparatively stable, and the ground-wave of the transmission, which is, of course, not affected by changes in the ionosphere, is received over a useful area. Results[1] obtained at the National Physical Laboratory show that this transmission can be used in the United Kingdom with an accuracy of $\pm$ 1 part in 10^9 in an observation time of a few minutes; and in spite of its low power of 10 kW., it has been received and measured at Harvard University with the same precision by a somewhat different technique in a time of about 10 min. Higher accuracies of comparison can be obtained by averaging the observations over longer periods.

The *MSF* transmissions are operated from the Post Office Radio Station at Rugby, where the powerful 16 kc./s. transmitter *GBR* is also located. The carrier wave of this transmitter is now controlled by the standard used for the *MSF* transmissions in order to facilitate measurements at great distances whenever *GBR* is in operation.

A typical photographic record taken at Harvard and including the results obtained with both the 60 kc./s. and the 16 kc./s. transmissions is reproduced as Fig. 1. The edge of a dark band represents the arrival time of a particular phase of the carrier wave on a time-scale derived from the local standard; and when it forms a horizontal line the frequency of the received signal is in exact agreement with that of the local standard, or is in simple relationship with it, such as 16/100 and 60/100 in this case. The slope corresponding to a deviation from the local value of 1 part in 10^9 has been indicated in the diagram. The smoothness of the edges of the trace demonstrates that the propagation path is relatively free from short-period fluctuations, but the changes in slope are due to gradual changes in the height of the reflecting layer. Closer checking by independent means of the frequency of the local standard will enable the frequency changes associated with the diurnal movements of the layer to be accurately measured and compensated in the frequency comparisons.

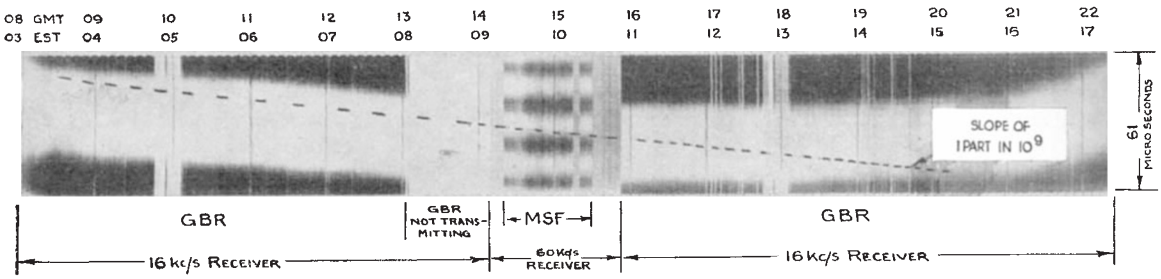

Fig. 1

These results, which will be reported more fully elsewhere, are clearly of significance in problems of frequency control, international frequency and time standardization, and navigational aids based on phase comparison; and the possibility of securing comparisons of frequency and therefore of time-interval to a precision of $\pm$ 1 part in 10^9 on a world-wide basis is probably also of interest in a much wider field. Measurements to this accuracy must at first be on a comparative basis, since the unit of astronomical time cannot be predicted with an accuracy greater than $\pm$ 1 part in 10^8; but this restriction may be removed if work on other possible units of time based on the natural resonant frequency of an atom proves to be successful.

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1 Essen, L., *Proc. Inst. Elect. Eng.*, **101**, Pt. III, 249 (1954).